

VHE γ -ray emission from the FSRQs observed by the MAGIC telescopes

E. Lindfors, K. Nilsson

Finnish Centre for Astronomy with ESO, University of Turku, Finland, contact: elilin@utu.fi

U. Barres de Almeida, D. Mazin, D. Paneque, K. Saito

Max-Planck-Institut für Physik, Munich, Germany

J. Becerra Gonzalez

Inst. de Astrofísica de Canarias, Spain and University of Hamburg, Germany

K. Berger

Inst. de Astrofísica de Canarias, Spain

G. De Caneva

DESY, Zeuthen, Germany

C. Schultz

Universita di Padova and INFN, Italy

J. Sitarek

IFAE, Edifici Cn., Campus UAB, Spain

A. Stamerra

Universita di Pisa, and INFN Pisa, Italy

F. Tavecchio

*INAF National Institute for Astrophysics, Italy
on behalf of the MAGIC collaboration*

S. Buson

INFN and Universita di Padova, Italy

F. D'Ammando

Univ. Perugia and INFN

M. Hayashida

*SLAC, California Institute of Technology, USA and Kyoto University, Japan
on behalf of the Fermi-LAT collaboration*

A. Lähteenmäki, M. Tornikoski

Aalto University Metsähovi Radio Observatory

T. Hovatta

Owens Valley Radio Observatory, California Institute of Technology, USA

Among more than fifty blazars detected in very high energy (VHE, $E > 100 \text{ GeV}$) γ -rays, only three belong to the subclass of Flat Spectrum Radio Quasars (FSRQs): PKS 1510-089, PKS 1222+216 and 3C 279. The detection of FSRQs in the VHE range is challenging, mainly because of their steep soft spectra in the GeV-TeV regime. MAGIC has observed and detected all FSRQs known to be VHE emitters up to now and found that they exhibit very different behavior. The 2010 discovery of PKS 1222+216 ($z = 0.432$) with the fast variability observed, challenges simple one-zone emission models and more complicated scenarios have been proposed. 3C 279 is the most distant VHE γ -ray emitting AGN ($z = 0.536$), which was discovered by MAGIC in 2006 and detected again in 2007. In 2011 MAGIC observed 3C 279 two times: first during a monitoring campaign and later observations were triggered by a flare detected with *Fermi*-LAT. We present the MAGIC results and the multiwavelength behavior during this flaring epoch. Finally, we report the 2012 detection of PKS 1510-089 ($z = 0.36$), together with its simultaneous multiwavelength data from optical to γ -rays.

1. INTRODUCTION

Blazars show variable emission in all wavebands from radio to γ -rays, but in FSRQs the variability is typically larger in amplitude. VHE γ -ray FSRQs are also more luminous in MeV-GeV band than the VHE γ -ray emitting BL Lac objects and in general also more distant. The spectral energy distribution (SED) of both subclass of blazars show two peaks: first peak is generally attributed to synchrotron emission and the second to inverse Compton scattering. Also hadronic mechanisms for producing the second

peak has been proposed [e.g. Böttcher et al. 2009]. In the case of FSRQs the first peak is typically in the infrared regime while for BL Lacs it is between optical and hard X-rays. The optical spectra of FSRQs show broad emission lines, implying an existence of fast moving gas clouds close (0.1 to 1 parsec) to the central engine, while BL Lacs show very weak or no emission lines in their spectra. Because of these properties, FSRQs were considered not to be good candidates to emit VHE γ -rays: the low synchrotron peak frequency implies efficient cooling [e.g. Ghisellini et al. 1998], which makes it difficult to produce VHE γ -ray

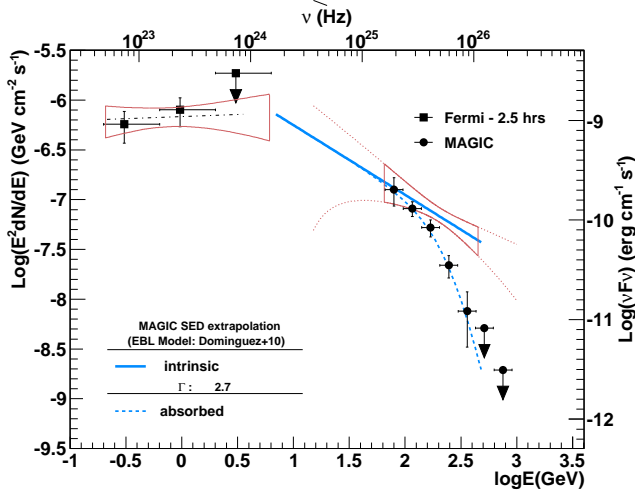


Figure 1: PKS 1222+216: The high energy SED of the flare of 2010 June 17th. The rectangular data points report the *Fermi*-LAT data of 2.5 hours observation centered around the 30 minutes observation by MAGIC (filled circles). The figure is adapted from [Aleksic et al. 2011a]

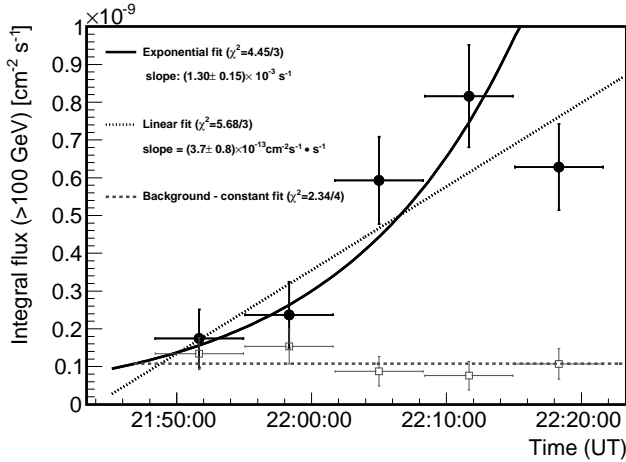


Figure 2: PKS 1222+216: The lightcurve of the flare above 100 GeV in 6 min bins. The figure adapted from [Aleksic et al. 2011a].

emission, the broad line region clouds absorb the γ -ray emission via pair production and the large redshift also means stronger absorption of VHE γ -rays by the extragalactic background light on their travel to earth. However, three FSRQs have been detected by the Imaging Air Cherenkov Telescopes (IACTs) and here we summarize the recent results of FSRQ observations from the Major Atmospheric Gamma-ray Imaging Cherenkov (MAGIC) Telescopes. MAGIC, operating in stereo mode since Fall 2009, is two 17 m IACTs sited on the Canary Island of La Palma at 2200 m a.s.l. Its energy threshold of 50 GeV in standard trigger mode is currently the lowest avail-

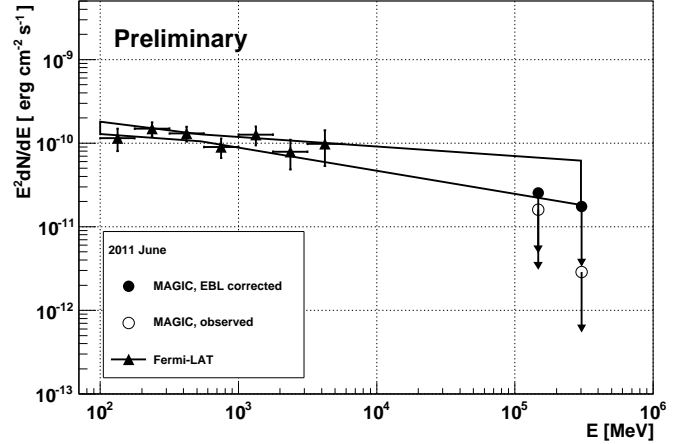


Figure 3: Spectral energy distribution of 3C 279 measured with *Fermi*-LAT and MAGIC in June 2011. The upperlimits from MAGIC are corrected for EBL absorption using Dominguez, et al. [2011].

able, and it has a sensitivity in stereo mode $< 0.8\%$ Crab Unit above 300 GeV in 50 hrs of observations [Aleksic et al. 2012].

2. PKS 1222+216

The blazar PKS 1222+216 (4C +21.35) was discovered at VHE γ -rays by MAGIC on June 17th 2010 [Aleksic et al. 2011a] during follow up observations triggered by high activity in high energy (HE) γ -rays in the *Fermi*-LAT range. MAGIC measured a soft spectrum with a photon index $\Gamma = 3.75 \pm 0.27_{\text{stat}} \pm 0.2_{\text{sys}}$ in the energy range from 70 GeV to 400 GeV. Complementing the measurements with *Fermi*-LAT observations, the simultaneous GeV and VHE (corrected for EBL absorption) spectra are consistent with a single power law with an index of 2.7 ± 0.3 between 3 GeV and 400 GeV, without a strong intrinsic cut-off (see Fig. 1). This strongly suggests that the γ -ray emission is located beyond the BLR. The VHE light curve (Fig. 2) shows a flux doubling time of the flare of the order of 10 minutes, among the fastest variations ever detected for sources of this class, implying a compact emission region, which is difficult to reconcile with a scenario where the γ -ray emission is not produced inside the BLR.

3. 3C 279

3C 279 was discovered at VHE γ -rays by MAGIC on February 23rd 2006 [Albert et al. 2008] and re-detected on January 17th 2007 [Aleksic et al. 2011b]. Both observations took place during optical high

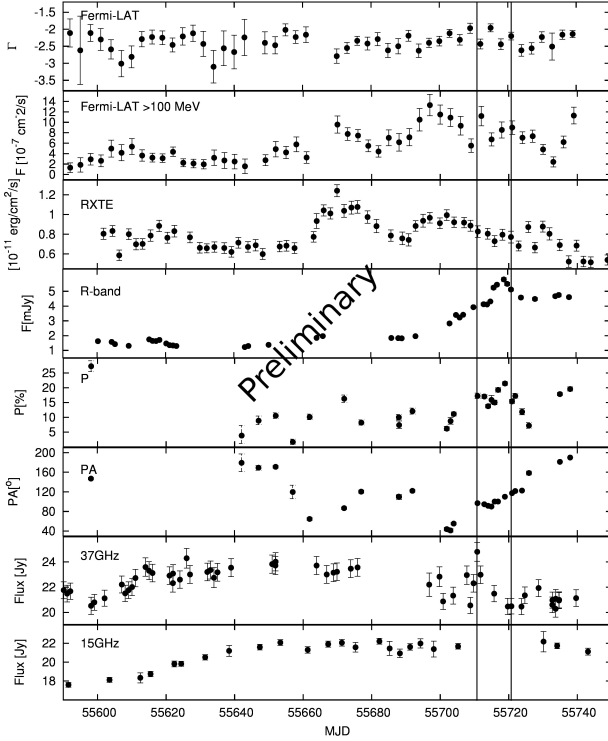


Figure 4: The MWL light curve of 3C279 from radio to γ -rays. The vertical lines indicate the MAGIC observing epoch in June 2011.

state, in particular 2007 observations during a major optical outburst (largest one observed in the past 10 years from the source). In the spring of 2011 3C 279 was showing increasing optical flux, as well as increased γ -ray flux as observed by *Fermi*-LAT, which triggered MAGIC observations of the source. The MAGIC observations did not yield in a detection, but provided tighter upper limits at VHE with respect to previous MAGIC observations performed in 2009 [Aleksic et al. 2011b]. These upper limits together with the simultaneous Fermi spectrum suggests a break in the spectra at > 10 GeV.

The multiwavelength light curves from radio to γ -rays (Fig. 4) show complex behavior. In γ -rays there are three flares, the brightest one peaking on MJD 55698. In X-rays there are two flares which are simultaneous to γ -ray flares observed by *Fermi*-LAT. The optical outburst starts around the time when the second flare in γ - and X-rays is peaking and is accompanied by an increase of the optical polarization and a rotation of the polarization angle. While the MAGIC observations missed the largest γ -ray peak, there was still small γ -ray flare in this epoch whereas in X-rays the source was already decaying smoothly. The radio light curve indicates a fast flare at the beginning of the MAGIC observing epoch.

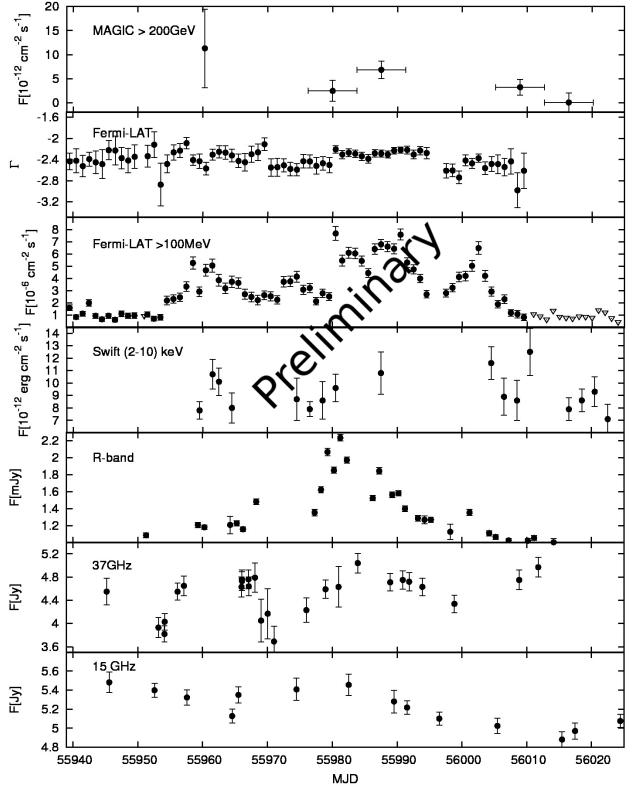


Figure 5: The MWL light curve of PKS 1510-089 from radio to VHE γ -rays in spring 2012.

4. PKS 1510-089

Following the communication from the *Fermi*-LAT and AGILE collaborations, PKS 1510-089 was observed by MAGIC starting on February 3rd 2012. The observations continued until April 3rd 2012. These observations resulted in a detection of VHE γ -rays from the source with $> 5\sigma$ significance [Cortina 2012]. The source had been previously detected to emit VHE γ -rays by the H.E.S.S. telescope array in 2009 [Wagner 2010] during a major optical outburst. The optical outburst observed in February-March 2012 was almost an order of magnitude smaller, but still the second brightest in the Fermi era. Unlike the other FSRQ detections by MAGIC, PKS 1510-089 signal comes from several nights. The analysis of the MAGIC data is ongoing and will be combined with radio (F-Gamma, Metsähovi, OVRO, VLBA), optical (KVA, Liverpool), X-rays (*Swift*) and γ -rays (*Fermi*-LAT, AGILE) in the upcoming publication. Part of the multiwavelength light curves is shown in Fig. 5.

5. SUMMARY

The three known VHE gamma-ray emitting FSRQs, namely PKS 1222+216, 3C 279 and PKS 1510-089,

have been observed and detected by MAGIC:

1. The detections have all taken place during the activity in the lower energy regimes, but some of the observations in high optical and γ -ray states have only resulted in flux upper limits.
2. The activity in the lower energy regimes has not followed the same patterns during the four VHE detections.
3. The three sources show different time scales of variability in VHE gamma-rays.

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